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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Prescribes procedures for evaluating vehicle steering systems. Describes cramping angle and steering ratio measurement. Includes tests for turning, overall steering performance, lane changing, drift, dead engine steering, control on slopes and adverse terrain, and human factors evaluation. Applicable to land steering of wheeled, tracked, and amphibious vehicles.

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US ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

DRSTE-RP-702-101
*Test Operations Procedure 2-2-609 | 18 July 1980
AD No.

STEERING

1. SCOPE. This TOP provides procedures for evaluating the steering performance of wheeled and tracked vehicles. Procedures are limited to steering systems for expected land use. For other applications - e.g., swimming, negotiation of obstacles, operation in extreme temperature environments - the steering system is evaluated by the particular test procedure that is pertinent.

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities. The courses listed below are those located at Aberdeen Proving Ground and are described in TOP 1-1-011. Equivalent courses may be used.

ITEM	REQUIREMENT
Turning circle (Paragraph 5.2)	A flat, concrete surface, large enough for the largest wheeled and tracked vehicles
Endurance test courses (Paragraph 5.3)	Applicable courses as identified in TOP 2-2-506
1-Mile steering performance course	Composed of selected Munson area test courses (Paragraph 5.3)

AD 34033

*This TOP supersedes TOP 2-2-609, 6 January 1976.

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ITEM (CONT)	REQUIREMENTS (CONT)
Lane changing and drift test course (Paragraphs 5.4 and 5.5)	A straight, level, paved road with lane dividing line marked (same as high-speed paved road in TOP 1-1-011)
Dead-engine-steering courses (Paragraph 5.6)	Gravel road test course; gradeability (longitudinal grades) test courses as specified from vehicle gradeability tests (TOP 2-2-610)
Side slope test courses (Paragraph 5.7)	Hard-surfaced, 20%, 30%, or 40% slope depending on vehicle design and specification
Adverse terrain courses (Paragraph 5.8)	Sand course, abrasive mud course, wave course, staggered bump course, depending on test requirements

2.2 Instrumentation.

ITEM	MAXIMUM ERROR OF MEASUREMENT*
Distance measuring device	±0.3 m (±1 ft)
Wheel alignment service unit (Paragraphs 3.1.1 and 5.1)	±1/4° - Caster, camber, and toe-in ±1° - Cramping angle
Engine tachometer	±0.5% of full scale range
Vehicle speed measuring device	±0.2 km/hr (mph)
Timing device (stopwatch or other suitable timer)	±0.1 sec
Temperature measuring equipment (Paragraph 5.3)	±1°C (±2°F)
Pressure-strain instrumentation (Paragraph 5.3)	±1% of full scale range
Device for measuring steering wheel displacement (Paragraph 5.3)	±2% of full scale range

*Values may be assumed to represent ±2 standard deviations. Thus, the stated tolerances should not be exceeded in more than 1 measurement out of 20.

3. PREPARATION FOR TEST.

3.1 Test Item.

3.1.1 Inspection. The test vehicle is inspected as described in the applicable sections of TOP 2-2-505. For wheeled vehicles, particular attention is given to wheel alignment, steering mechanism adjustments, and tire pressures. For tracklayers, the transmission must function properly in all ranges; the item differential, if applicable, must be properly adjusted; suspension components must be in good condition; and tracks must be properly adjusted and not worn to the extent that steering is affected.

3.1.2 Break-In. New vehicles are operated for the appropriate break-in mileage as specified in TOP 2-2-505. Any mechanism adjustments required are made during or at the conclusion of the break-in period.

3.1.3 Test Loads. Unless otherwise specified, the vehicle is loaded with its maximum rated payload or combat weight.

3.2 Instrumentation. The instrumentation to be installed on the vehicle depends upon the particular tests to be conducted. The vehicle usually is instrumented for test course operation to record engine speed using an engine tachometer and vehicle speed using a calibrated tachometer generator actuated by the vehicle speedometer drive cable. When a more detailed evaluation is required, additional instrumentation is installed to measure steering effort, wheel position, and fluid pressure and temperature of the steering system as described in Paragraph 5.3.

3.3 Data Required. The following data are recorded during test planning or at the time the subtest is conducted (performance data to be obtained are indicated with the subtests, Paragraph 5):

3.3.1 Facilities. Test course identification/description.

3.3.2 Test Item. Vehicle identification and tire data (type, size, identification number and tread depth) or applicable track data are recorded as well as payload weight, break-in mileage, and any adjustments after break-in as indicated above.

3.3.3 Instrumentation. Type, nomenclature, accuracy, and location of instrumentation.

4. TEST CONTROLS. A preselected number of qualified vehicle drivers are rotated among test vehicles to reduce the effect of driver bias in steering evaluations. The number and frequency of rotations are specified in the test plan.

Correct levels of lubricant, hydraulic fluid, coolant, etc., are maintained throughout testing.

5. PERFORMANCE TESTS. Performance requirements for steering vary with the design and mission of the vehicle, and the extent to which these are quantitatively stipulated also varies with different military specifications. Performance characteristics that are evaluated quantitatively

generally include the turning radius, the steering ratio, and the steering effort. Other aspects of performance, such as human engineering, are evaluated qualitatively during operational trials. All aspects of steering are evaluated either by physical measurement or by the systematic collection of the judgments of a group of representative drivers.

5.1 Cramping Angle and Steering Ratio.

5.1.1 Method. Determine the maximum angle, i.e., cramping angle, through which the wheels of the steering axle can be deflected from the straight-ahead position to maximum left and maximum right. Measurement is best accomplished using a wheel alignment service unit. For the maximum left position, measure the cramping angle at the left wheel (fig. 1); for the maximum right position, make the measurement at the right wheel. Count the number of turns of the steering wheel required to move the wheels from one extreme to the other (maximum left to maximum right or vice versa). Check wheel stops or other limiting devices for their ability to positively limit the cramping angle to the maximum angle specified.

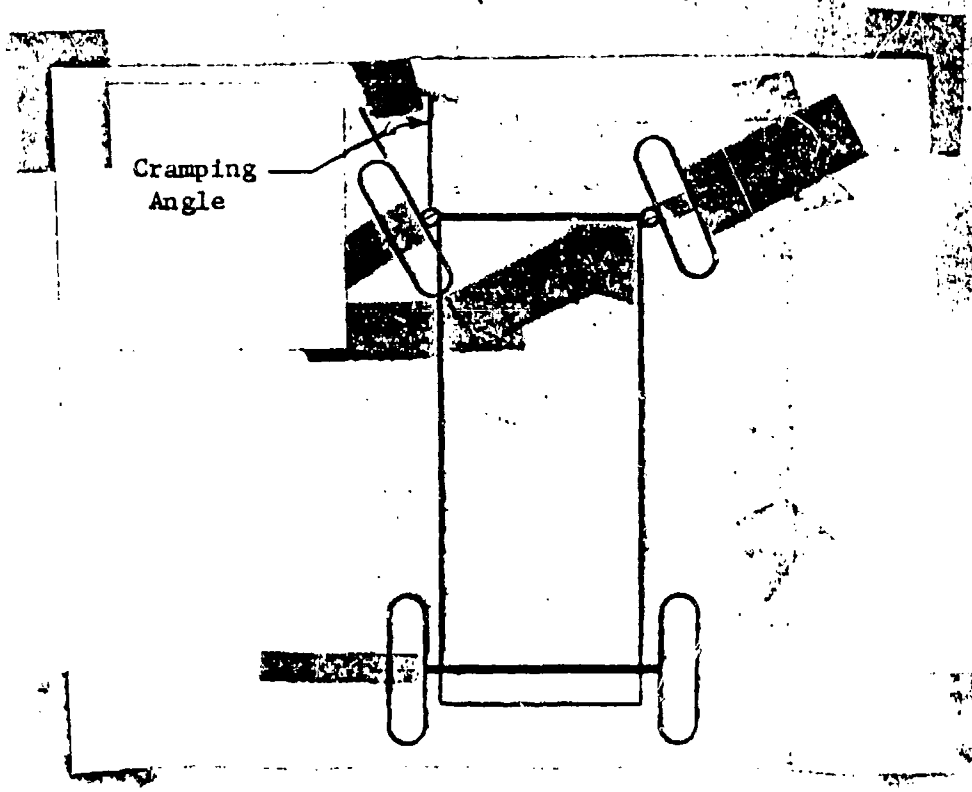

Figure 1. Cramping Angle.

For constant ratio steering systems, compute the steering ratio using the following equation:

$$\text{Steering Ratio} = \frac{N \times 360^\circ}{T_a} : 1$$

where:

N = turns of steering wheel
T_a = turning angle of front wheel, degrees (full angular change of front wheels from extreme left to right)

Example:

N = 2-1/3
T_a = 60°

$$\text{Steering Ratio} = \frac{2\text{-}1/3 \times 360}{60} : 1 = 14:1$$

For variable ratio steering systems, plot the degrees of turn of the steering wheel against the degrees of turn of the road-wheel and the ratio at any point in the steering range determined by the slope of the curve.

5.1.2 Data Required.

Left cramping angle, degrees; right cramping angle, degrees.

No. of turns of steering wheel, maximum left to maximum right.

Steering ratio.

Turning angle of front wheels from extreme left to right, degrees.

5.2 Turning. The turning ability of the steering system is indicated by the minimum circle that the vehicle can negotiate and, when required, the minimum road widths into which the vehicle can turn.

5.2.1 Minimum Turning Circle. To determine the minimum turning circle, measure the following circumferences for the tightest turns in both directions on dry, concrete surfaces, operating the vehicle at minimum speed (unless otherwise specified):

"Curb-to curb" - circumference of the circle described by the outer edge of the outside front wheel or track.

"Wall-to-wall" - circumference of the circle described by the outermost point of the vehicle when turning at maximum angle. A small wheel or a water spray at outermost point is usually used. For tanks, the test is conducted with gun horizontal both in 12 o'clock and 6 o'clock positions.

For wheeled vehicles take a third measurement, the circumference of the "turning circle" taken to the center of the tire contact of the outer wheel (Figure 2), when required.

Measure turning circumferences of prime movers both with and without the towed load or trailer. Observe air lines, electrical wires, towbar, safety chains, and the towed load or trailer itself for any interference that would limit the measured turning circle.

For tracked vehicles having more than one type of steering - e.g., gear and clutch-brake, pivot - measure the circumference formed by each type of steering.

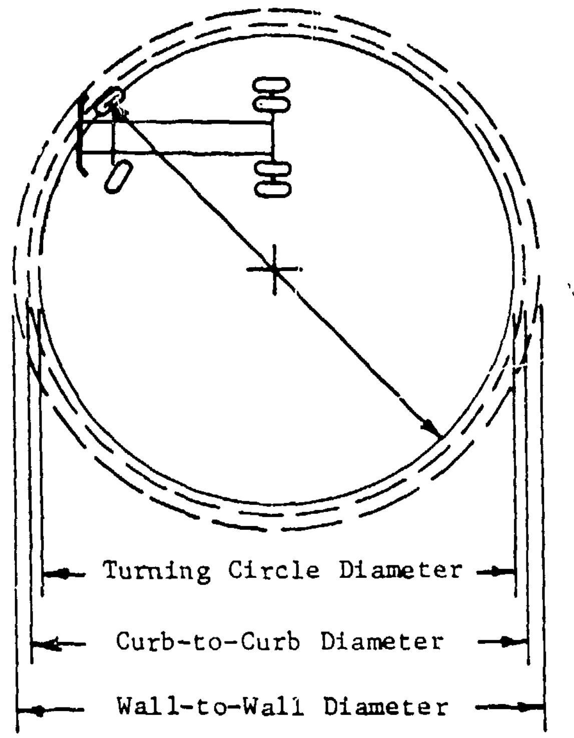

Figure 2. Minimum Turning Measurements.

5.2.2 Minimum Road Width. Set up pylon markers to outline a 90-degree turn course with W representing road width (fig. 3). Assume in one instance that there are curbs with no buildings and in the other that buildings extend to street edge. For each condition decrease the width of the roads until the minimum road width into which the vehicle can turn is determined for both right and left turns of the vehicle. For tanks, the test is conducted with the gun horizontal, in both the 6 o'clock and 12 o'clock positions.

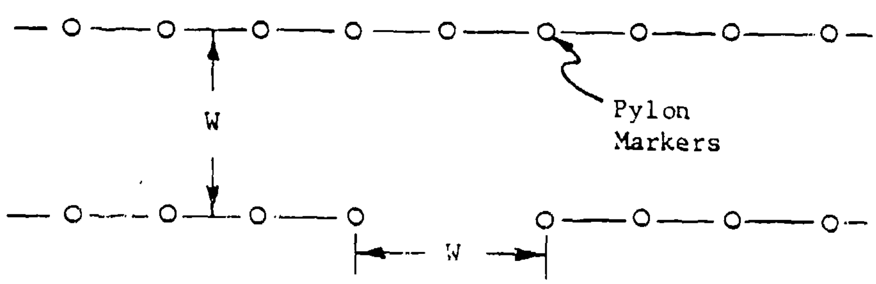

Figure 3. Ninety-Degree Turn Course.

5.2.3 Data Required. Determine the following as applicable:

Minimum turning circle diameters (both directions).

Interferences limiting measurement.

Minimum road widths for left and right 90-degree turns (curb-to-curb and wall-to-wall).

5.3 Overall Steering Performance. Evaluate the overall steering performance of the vehicle under conditions of expected vehicle deployment during the vehicle endurance test (TOP 2-2-506). When further investigation is needed, tests are made on the steering performance course.

5.3.1 Method. During the endurance test observe and evaluate the overall steering performance including the steering effort required by the driver and the responsiveness of the vehicle (driver control) under each condition of deployment (e.g., terrain, load, temperature, vehicle and engine speeds).

When steering effort appears to be excessive, control is questionable, or a particular capability of the steering system requires investigation, conduct a more detailed evaluation of steering performance on the 1-mile steering performance course (Figure 4) with the vehicle instrumented to measure driver effort on the steering wheel (using a strain-gaged steering wheel clamped to the standard steering wheel), steering wheel position (if possible, by using a potentiometer actuated by a constant torque-negator motor attached to the steering wheel), and fluid temperature and pressure in the hydraulic steering mechanism (when applicable). Constantly record and identify the measurements according to maneuver or event (i.e., figure-eight turns, percent slope, etc.) as the vehicle negotiates the course in both directions at maximum safe speeds.

5.3.2 Data Required. Record the following as applicable:

Observations and evaluations of steering performance during endurance operations on various terrains.

For each maneuver or event on the steering performance course: maximum steering wheel effort, maximum steering wheel displacement (degrees), speed range, and maximum fluid temperature and pressure.

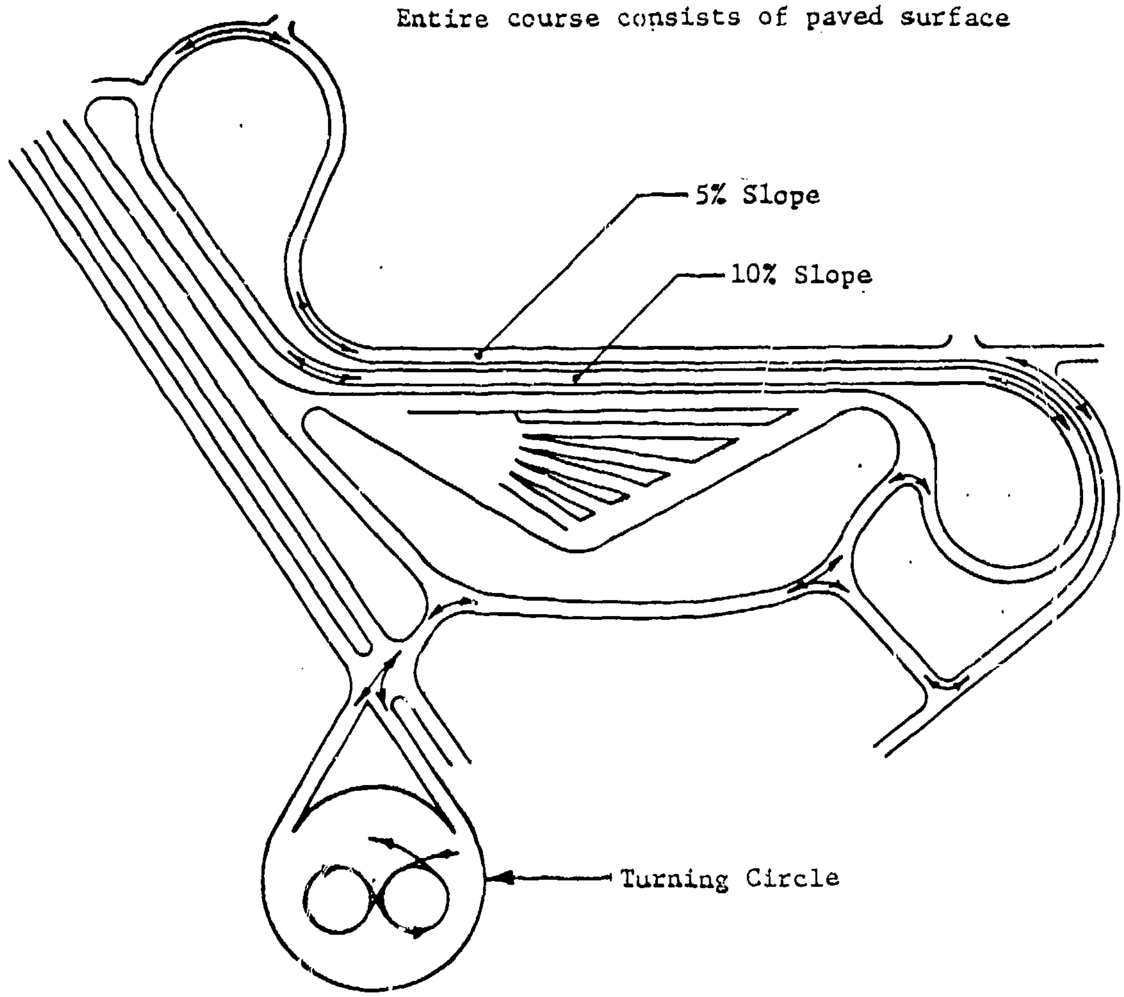

Figure 4. Steering Performance Test Course, Munson Test Area, Aberdeen Proving Ground.

5.4 Lane Changing.*

5.4.1 Method. To evaluate the ability of a vehicle to change lanes, operate the vehicle on a zig-zag course - a straight, level, paved road marked off as in figure 5 - at increasing speeds until the maximum safe speed is attained in the opinion of the driver. (Distance (D) is equal to one and one-half times the minimum turning circle diameter for the particular vehicle.) Record the time required to leave one lane, enter an adjacent lane, and return to the original lane, and the speed attained. Run sufficient trials with different drivers to insure consistent results.

*This subtest is not essential to every test program, but may be conducted at the discretion of the evaluator.

When delays appear excessive - i.e., significantly varying from lane-change time required for comparable vehicles - make detailed studies showing response time as functions of vehicle speed, engine speed, vehicle load, and transmission ratio.

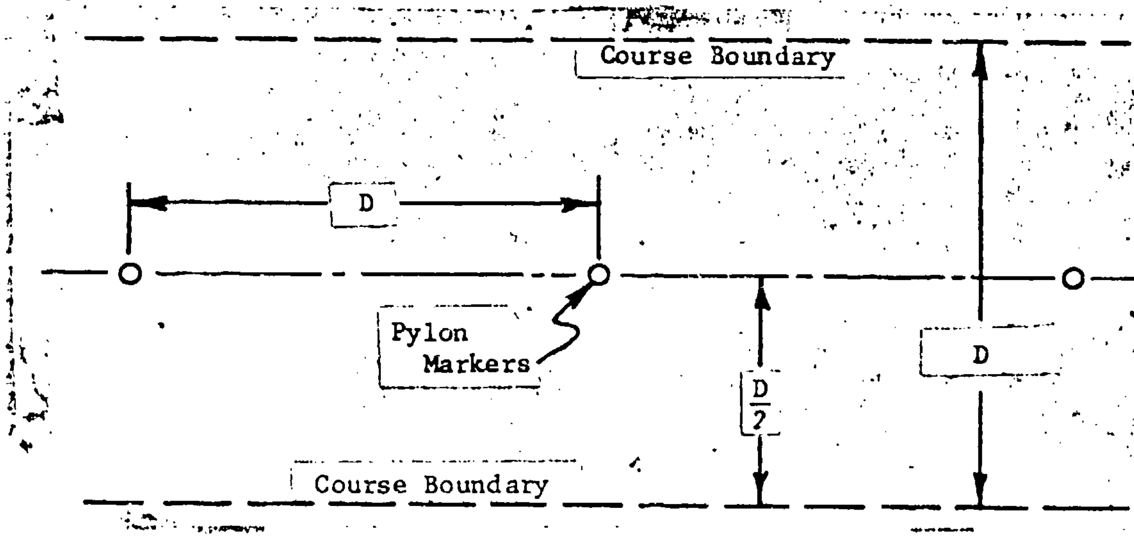

Figure 5. Zig-Zag Course Distances.

5.4.2 Data Required.

Distance between pylons.

Time to change lanes for each speed and each test run.

When applicable (excessive delays), for comparison purposes: response time versus vehicle speed, engine speed, vehicle load, and transmission ratio.

5.5 Drift.* Drift is the tendency of a vehicle to turn off slightly from a straight-ahead path when the vehicle steering wheel is allowed to assume its own self-centering position. Drift as measured in this test is that caused by the vehicle itself - e.g., from wheel alignment, asymmetrical loading, or a soft tire - as opposed to vehicle drift induced by the crown of the road, banked curves, or other outside influence. While some runs may be made with asymmetric loading and a soft tire, at least one must be made with a balanced load and properly inflated tires.

5.5.1 Method. While operating the vehicle on a straight, level road, release the steering wheel and record the amount of drift from a straight path per 30 meters of travel or by similar measurement reference.

5.5.2 Data Required. Record the amount of drift in meters versus distance traveled, tire pressures and some indication of load distribution.

*See footnote on page 8.

5.6 Dead-Engine Steering.* In addition to undergoing standard tests, power steering systems are evaluated for their ability to provide steering control, through either manual operation or an auxiliary power source, with the engine inoperative (provided that steering is a function of engine operation). This dead-engine steering ability is evaluated on a gravel road such as the Munson course at Aberdeen Proving Ground.

5.6.1 Method. On the gravel road, shut off the engine at predetermined speeds up to maximum safe speed and attempt a sinusoidal steer pattern until the vehicle stops.

5.6.2 Data Required. Record speeds and capability of the vehicle steering system to maintain directional control until the vehicle stops.

5.7 Control on Side Slopes. Vehicle steering on side slopes is evaluated during the conduct of the side slope tests of TOP 2-2-610. The 20-, 30-, or 40-percent hard-surfaced side slopes are used depending upon the vehicle design and specifications.

5.7.1 Method. Operate the test vehicle the length of the specified side slope in both directions. When testing cargo vehicles, load them to a maximum rated payload having a density of 897 kg per cubic meter (56 pounds per cubic foot) unless specified otherwise (e.g., some specifications call for a density of 385 kg per cubic meter (24 pounds per cubic foot).

Observe and record the maximum safe vehicle maneuverability (e.g., traversing in a sine wave pattern from one extreme to another on the side slope) and tire roll characteristics.

5.7.2 Data Required.

Grade of slope.

Load weight as applicable.

Vehicle speed.

Tire inflation pressures.

Driver's judgement on degree of control maintained in each condition.

5.8 Control on Adverse Terrain.* The effects of various terrain conditions on steering control are evaluated by operating the vehicle in terrain environments that typify projected vehicle use; e.g., mud, sand, ice, snow.

*See footnote on page 8.

5.8.1 Method. For these tests, use traction-assist devices when appropriate and specified. Use a tachometer for measuring engine speed, particularly on vehicles with power-assist mechanisms.

An all-wheel-drive vehicle may encounter difficulty in steering in mud or snow. To test steering effectiveness in mud or snow oscillate the steering alternately between extremes of left and right steer. Recovery of mobility by this method will be particularly evident in an articulated vehicle and certain other vehicles depending upon transmission design. Observe effects on tracks and suspensions, especially with respect to sprocket slipping, track throwing, and excessive accumulation of soil and debris.

Evaluate wheeled vehicle steering systems on the wave (frame twister) and staggered bump courses (TOP 1-1-011) in addition to the weather-induced adverse terrains above. Observe for any interferences, bindings, weaknesses, or other unsatisfactory features of the system.

Check conformance of standard systems with specifications as well as qualitatively. Conduct more detailed testing on newly developed systems, including comparison with existing systems. When steering efforts are measured in environments more severe than those of accepted standards, quantitative measurements are required, using instrumentation appropriate for the condition.

5.8.2 Data Required. Record the observations and evaluations of the drivers and test director relative to response and control of steering for each terrain condition.

5.9 Human Factors Evaluation. Throughout all testing, make observations and collect data in accordance with HEDGE 1/ and MIL-STD-1472B 2/ to support the overall human factors evaluation of the vehicle. Assessments are made as required of the following:

a. Steering sensitivity of the vehicle in terms of input/output gear ratio (i.e., does it tend to over or under steer).

b. Driver fatigue, objectively measured in terms of frequency and force of control inputs, and subjectively assessed from questionnaires, task checklists, and interviews.

c. Control response time lag, measured in terms of the suitability of the response time with regard to the speed of the vehicle and the magnitude of the required direction changes.

1/ HEDGE, "Human Factors Engineering Data Guide for Evaluation," US Army Test and Evaluation Command, March 1974.

2/ MIL-STD-1472B, "Human Engineering Design Criteria for Military Systems, Equipment and Facilities.

d. Complexity of operation in terms of the actual control movements necessary to operate the vehicle.

e. Convenience and safety of control locations.

f. Driving visibility to the front, rear, and sides, and at night. Visibility at night (TOP 2-2-616) is evaluated by repeating daylight test operations at various ambient light levels from darkness-full moon to dark overcast; time of test and light level or description are recorded.

5.10 Turning Speed.* This test determines the shortest time necessary to make a 360° turn.

5.10.1 Method. The engine is brought to nominal rpm and the steering is turned to maximum left or right position. Tests are conducted on a level concrete surface. The time that it takes to turn 360° from a stop is measured with a stop watch. The test is repeated as necessary.

5.10.2 Data Required.

Gear range.

Rpm of engine at start.

Time to complete 360° turn.

Angular velocity in rad/sec.

6. DATA REDUCTION AND PRESENTATION. The data obtained for each subtest are presented in tabular form.

Recommended changes to this publication should be forwarded to Commander, US Army Test and Evaluation Command, ATTN: DRSTE-AD-M, Aberdeen Proving Ground, MD 21005. Technical information may be obtained from the preparing activity: Commander, US Army Aberdeen Proving Ground, ATTN: STEAP-MT-M, Aberdeen Proving Ground, MD 21005. Additional copies are available from the Defense Technical Information Center, Cameron Station, Alexandria, VA 22314. This document is identified by the accession number (AD No.) printed on the first page.

*See footnote on page 8.